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Research on the Properties of Outsole Materials Composed of Waste Leather Fibers, Waste Fabric Fibers and Natural Rubber

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Abstract

Recycled materials are currently receiving significant attention from society. In particular, a large amount of waste is generated during the production process in the textile and footwear industries. New products have been developed by combining textile and footwear waste with plastic or rubber. In the study, the authors used fiber (fabric waste torn into fibers), leather waste, and natural rubber to successfully manufacture outsole materials by combining these three primary materials with additional additives and chemicals. After production, the properties of the product were tested. This article presents the results of a survey on the tensile strength, tear strength, hardness, water resistance, dimensional stability, abrasion resistance, and compression performance of the shoe outsole materials produced by Vietnamese Standards. Based on this research, we aim to develop shoe outsole materials that are in line with the principles of the circular economy of the Textile and Footwear industry and establish a domestic secondary raw material source for footwear manufacturing companies in Vietnam.

Keywords: Fabric waste, leather waste, outsole, recycled materials.

1. Introduction

The Textile and Footwear industry has long played an important role in economic development and solving social security issues in Vietnam. Besides the great contributions to the economic development of the country, the production activities of the Textile and Footwear industry also bring many negative impacts on the ecological environment. The production process of this industry involves a complex technological chain and various production methods that simultaneously utilize raw materials and chemicals, resulting in a wide range of items with diverse designs, colors, and types. However, this industry also generates a significant amount of fibrous waste that is non-decomposable and perpetually contaminates the soil and groundwater system [1, 2].

Waste management and treatment in the Textile and Footwear industry is a hot issue and a big problem for society. Therefore, the Textile and Footwear industry is encouraged to develop cleaner technologies that minimize waste while creating and maximizing product functionality. Aligned with the policy of greening the Textile industry, the use of fiber materials derived from waste generated during the production processes of Textile and Footwear enterprises as reinforcement components for industrial and civil applications has been and continues to be researched. This approach has attracted the attention of many authors worldwide and in Vietnam [3, 6]. The manufactured products offer not only good features but also lower prices. This is because utilizing textile waste as the main ingredient, instead of relying solely on potentially expensive raw materials, reduces the volume of input materials while maintaining good product properties, ultimately contributing to cost reduction. Many products have been successfully researched from combining scrap leather with plastic substrates to creating plastic films for agricultural applications [7]. Another study also used natural rubber latex as a binder for leather waste ground into powder to develop a low-cost composite material. The newly formed material has a smooth surface and good mechanical properties such as tensile strength, elongation at break, and tear strength, and can change color depending on the intended use in footwear, handbags, industrial interior materials, etc [8].

Another study by Portuguese authors [9] also looked at outsoles and recycled materials. They used a comparative life cycle assessment between traditional plastic and rubber outsole materials and cork shoe sole materials to study the environmental impact of each. The results showed that cork had a lower environmental impact, resource use, and emissions in each stage of the outsole life cycle and therefore acted as a viable sustainable alternative to plastic and rubber.

Consider the structure of the shoe product consisting of many parts such as the shoe upper and sole.

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Depending on the type of shoe, the shoe parts can be divided into: insole, which is the lining that directly contacts the foot and often has a soft cushion for increased comfort; midsole, the most important part that helps absorb shock and creates a soft feeling; and outsole, which features spikes, fishbone or honeycomb patterns to improve adhesion and prevent slipping.

The shoe's outsole plays an important role in ensuring the durability, performance, and aesthetics of the shoe. As the part that directly contacts the ground, the outsole helps create grip and friction, preventing slipping, especially important for sports shoes, safety shoes, or climbing shoes. In addition, the outsole also has the function of protecting the foot from impacts from hard surfaces, while reducing wear to increase the life of the shoe.

Furthermore, the outsole contributes to comfort during movement by employing reasonable shock absorption technology to provide maximum support for the user. In the field of sports, outsoles also help optimize performance and increase force and stability, supporting users to achieve better efficiency in movement activities. In general, outsoles not only play a protective role but also affect the user experience, from technical features to value.

The material used to make the outsole of a shoe plays an important role in determining the durability, abrasion resistance, and comfort of the shoe. Among them, rubber is one of the most popular materials that supports elasticity, good grip, and the ability to withstand all external factors such as rough ground or rocky roads, sharp objects, spikes, temperature, humidity, and cold when walking. Therefore, the desired properties in the outsole material are abrasion resistance, softness for comfort when walking, and insulation. Rubber soles outperform all other sole materials in terms of better performance and lower cost [10]. In addition, rubber and polyurethane (PU) are also a popular type due to their high durability, good bearing capacity, while still ensuring lightness and flexibility, often appearing in fashion shoes or office shoes. Some high-end shoe lines also use ethylene-vinyl acetate (EVA) material, a super-light plastic that has good shock absorption, helping to increase comfort when changing direction.

In modern designs, major brands also research and apply advanced materials such as compressed air foam, carbon fiber, or even recycled rubber to optimize product performance and sustainability. The choice of external materials not only affects the user experience but also determines the application of the shoe.

Currently, with the development of the Textile and Footwear industry, the high rate of input material usage means that the amount of solid waste produced each year reaches thousands of tons. This poses a significant problem for society. This is why the Textile and Footwear industry has been encouraged to adopt cleaner technologies by minimizing waste and maximizing product functionality. However, the generation of solid waste is inevitable, as waste output increases with the scale of production. Among the types of solid waste in the Textile and Footwear industry, scrap leather represents a significant proportion. Disposing of scrap leather not only exacerbates environmental issues but also wastes a source of fibers, scrap fabric, and collagen fiber (the main component of leather) that artificial materials cannot replicate.

To manage and treat waste in the Textile and Footwear industry, several solutions have been proposed, including reducing product use, recycling and recovering those products, and combining them with other materials to create new ones. The research group is focused on the direction of "combining with other materials to create new materials". Utilizing fibrous materials, particularly industrial and agricultural waste and by-products, as reinforcement components not only produces materials with desirable properties but also reduces costs. Using 100% imported input materials can be expensive, whereas textile waste as the main component decreases the volume of input materials and contributes to cost reduction.

The research team aims to use the main raw materials as fibers derived from crushed fabric scraps (torn into fibers) and crushed leather fibers, which will then be blended with a rubber base along with other additives and chemicals, employing methods for creating composite materials. Incorporating scrap as a primary ingredient in the material mixture significantly decreases the amount of rubber required, leading to lower product costs.

This article builds upon the previous work of the research group [11, 13] which explored the use of rubber materials, waste textile fibers, and waste leather fibers. Specifically, this article presents the results of a survey of some mechanical properties, water resistance, dimensional stability, and compression of shoe outsole products according to Vietnamese standards (TCVN). This research identifies suitable technology for manufacturing shoe outsoles from scrap materials within the Textile and Footwear industry.

2. Experiment

2.1. Materials

a. Chemicals: Zinc oxide, stearic acid, sulfur, disulfit benzothiazil, diphenylguanidin.

b. Materials: 3 L natural rubber, textile waste fibers, leather waste.

3L natural rubber: produced in Vietnam. Natural rubber exhibits high adhesive strength, good rolling and injection molding capabilities, and minimal shrinkage in product size.

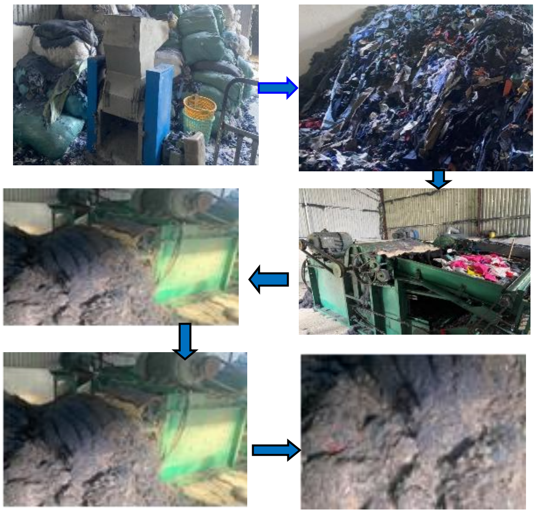

Fig. 1. Shredding scrap fabric

Fig. 2. Shredding of waste leather fibers

2.2. Machine Settings

For scrap fabric: Choose shredding equipment that uses a roller crusher for scrap fabric intended as filler for shoe sole products. This type of machine has suitable parameters and characteristics to convert scrap into fibers for the final product. Shredding scrap fabric in Fig. 1.

Crushing roller motor: 4 kW/380V; Exhaust fan motor: 3 kW/220V; Conveyor motor: 0.75 kW/380V.

The scrap fabric consists of material with a polyamide (PA) composition. The scrap fabric is shredded using the dry method on a roller crusher, producing fabric fibers with widths of 0.5−1 mm and lengths of 10−20 mm.

For scrap leather fibers, there are various sizes; thus, we must sort and trim the scrap leather pieces into relatively uniform sizes before crushing. The dimensions of the leather pieces before crushing are cut to sizes of 3 cm × 5 cm, dried, and then processed in a hammer mill until short bunches of leather fibers measuring 0.1−0.2 mm in width and 3−5 mm in length are obtained. Shredding of waste leather fibers in Fig. 2.

The waste is collected during the production processes of textile and footwear factories in Hung Yen.

2.3. Method

Composite materials are made from three components: fabric fibers, waste leather fibers, and rubber to make shoe outsoles. They are independent materials bonded by a system of chemicals, such as accelerators and vulcanizing chemicals. In the technology of manufacturing shoe sole materials, factors such as mixing time, temperature, and mixing speed have a decisive influence on the structure and the properties of the composite materials. Therefore, based on the properties of the raw material components and the rheological properties of the composite materials, appropriate preparation and processing modes are selected.

The manufacturing method goes through several main stages, as shown in Fig. 3.

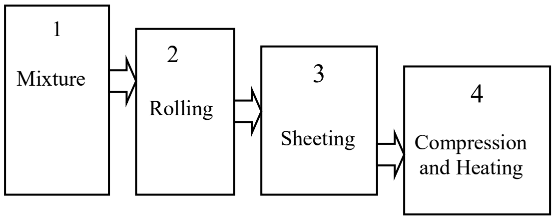

Fig. 3. Main technologies in making outsole materials

1-Mixing process.

Raw materials used for mixing are weighed and measured according to the ingredients, including rubber, chemicals, and recycled textile and footwear scraps. Mixing is carried out in the mixing chamber of a 75-liter closed mixer so that the chemicals and rubber are mixed evenly to form a homogeneous mass. The mixing time is 15 minutes, with the temperature of the mixing chamber of the closed mixer gradually increasing over time and reaching a temperature of 105 °C. Then it is poured out and put on the rolling mill.

2-Rolling mill process

The mixed material is put on the rolling mill, stirred evenly and thinned with a distance of 0.5 mm. It is cooled and discharged 4 times, then stirred evenly into a homogeneous mass and sent to the sheeting stage.

3-Sheeting process

After finishing the rolling and discharge process, the material is put on the sheeting system, according to the mold size and distances. When the product forms a unified block, the material surface is smooth, and the color is uniform; this sheeting process is finished.

4-Compression and heating

The product panels are mixed, cut, and put on the automatic stamping machine according to the available design drawings. Next, arrange the newly stamped layers into the compression mold according to the design drawings to make outsoles. The compression technology parameters are as follows: Pressing temperature is 150 °C; Pressing pressure: 70 kg/cm^2; Pressing time: 7 minutes; Cooling at room temperature: 20 °C − 30 °C.

After undergoing the same production process and using identical materials, five samples - L1, L2, L3, L4, and L5- were randomly chosen as outsole material samples to assess the durability of their properties. They were then taken to test the following properties: tensile strength, tear strength, hardness, water resistance, dimensional stability, and compression of the shoe outsole.

2.4. Measurements

Outsole material samples are tested according to the following standards.

Tensile strength is according to TCVN 6408:1998. The tensile strength of the product was determined on an INSTRON tensile machine (USA) in Fig. 4. The sample pulling speed was 100 mm/min at room temperature.

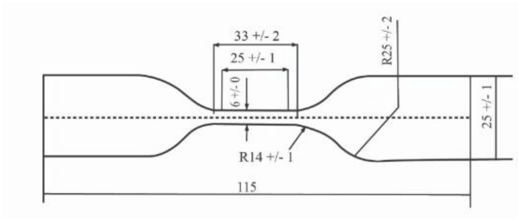

Fig. 4. Tensile test specimen cutting die

Tear strength according to TCVN 1597-1:2013 as shown in Fig. 5.

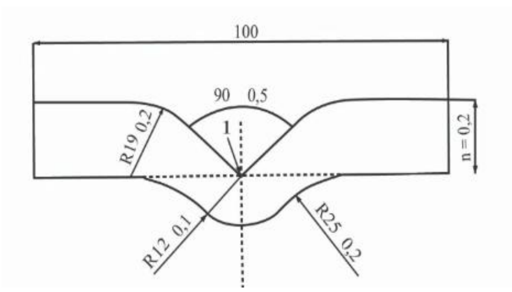

Fig. 5. Tear strength test specimen cutting die

Hardness (shore A) is determined by a Japanese TECLOCK hardness tester according to TCVN 1595-1:2013 in Fig. 6.

Outsole water resistance is according to TCVN 8840-2011.

Dimensional stability of outsole material samples is according to TCVN 12731:2019.

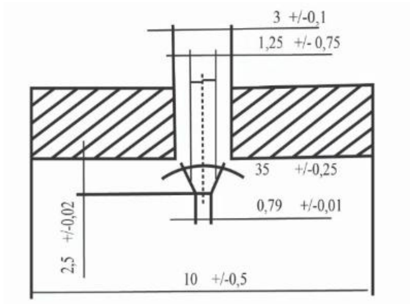

Fig. 6. Simulation of the hardness tester of the sample

Abrasion resistance is determined by the GTFO12D tester (Japan) according to TCVN 12731:2019.

Compression ability of outsole material samples is according to TCVN 10083:2013.

3. Results and Discussion

3.1. Results of the Mechanical Strength of Outsole Material

Combining natural rubber with waste fabric fibers and waste leather fibers presents many valuable properties, aiming at the primary goal of producing composite materials for use as outsole materials.

Therefore, it is essential to examine specific properties to evaluate the material's suitability based on the criteria for outsole materials. Based on those results, adjustments will be made to investigate the subsequent content sections.

The material samples are manufactured at the same ratio and under the same technological conditions as previously outlined.

To evaluate the quality of outsole material, the study examined the influence of rubber base on the properties of polymer composite materials using fabric fibers and waste leather fibers. The material samples were evaluated through properties such as tensile strength, tear strength, abrasion resistance, and hardness. The results of the influence of rubber base on the properties of the material are shown in Fig. 7.

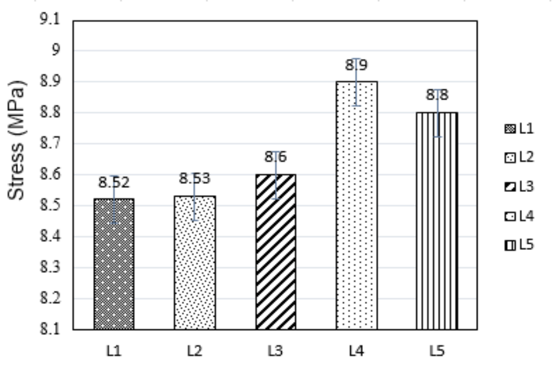

Fig. 7. Tensile strength of outsole material

3.1.1. Tensile strength

The results show that the outsole material samples made from textile and footwear waste exhibit a tensile strength between 8.52 and 8.9 MPa, which is favorable. The average tensile strength of the samples is 8.67 MPa.

First, the improvement in tensile strength may be attributed to the effective dispersion of waste fabric fibers and waste leather fibers within the rubber matrix, which significantly enhances the stress transfer of the composite material. Second, the compatibility of functional groups in leather fibers and those in rubber may explain the strong adhesion at the phase interface of waste fabric fibers, waste leather fibers, and the matrix when these fibers are incorporated into natural rubber.

This indicates that the bonds within the components are strong. The chains in the rubber have interacted with the -C-O- and -N-H groups in the collagen of the leather waste, enhancing compatibility and improving adhesion between the rubber and the scrap fibers.

3.1.2. Tear strength

The compatibility of waste fibers and natural rubber is again demonstrated by the tear strength results of the outsole samples in Fig. 8.

Testing of five standard outsole material samples found that the tear strength of the outsoles ranged from 52.2 N/mm to 60.8 N/mm. The average tear strength of the samples was 55.65 N/mm. The tear strength requirement of shoe sole materials according to TCVN 8840:2011 is greater than or equal to 8 N/mm. Tear strength is directly related to the development of cracks in the material. The trends in tear strength, both increasing and decreasing, closely resemble those of tensile strength. Research indicates that the presence of waste fibers significantly enhances tear resistance. Consequently, the composite bonds including those between waste fabric fibers and waste leather fibers, as well as between waste fibers and rubber play a crucial role in improving considerably tear strength.

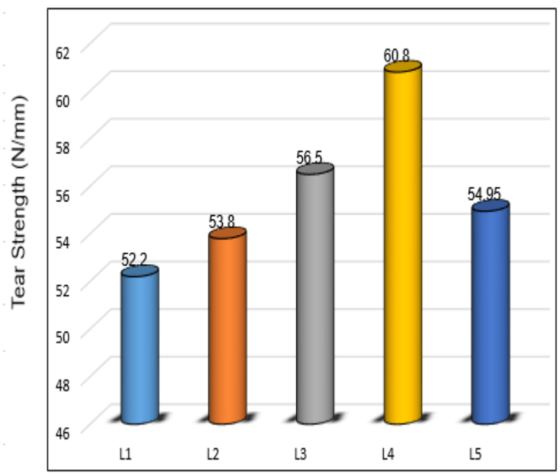

Fig. 8. Tear strength of outsole material

Thus, it can be concluded that the tested material samples have very good tear strength, meeting the requirements of outsole materials.

3.1.3. Hardness

Determining the stiffness of an outsole material is essential in footwear design and manufacturing. This directly affects the shoe's load-bearing capacity, durability over time, and stability on a variety of surfaces. An outsole with the right stiffness provides comfort and security for the wearer, enhances traction, and reduces the risk of slipping. Furthermore, stiffness is an important technical criterion used in product quality control to ensure performance and reliability. The compatibility of waste fibers and natural rubber is demonstrated by the hardness results of the outsole samples as shown in Fig. 9.

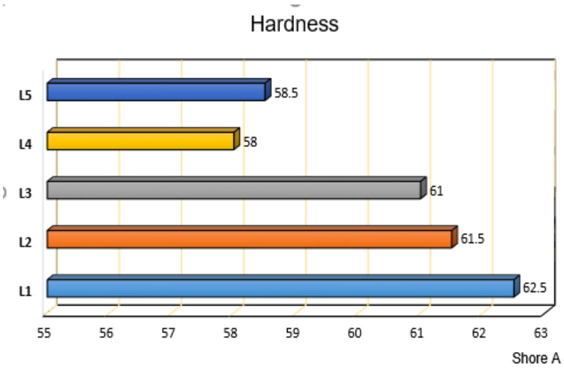

Fig. 9. Hardness of outsoles material

After manufacturing, the hardness of five outsole material samples made from textile and footwear waste L1, L2, L3, L4, and L5 was tested sequentially. The average hardness of the samples was 60.3 Shore A. Among them, sample L4 exhibited the highest tensile strength and hardness. The hardness test results indicated that incorporating waste leather fibers with a fiber bundle structure significantly enhanced the hardness of the composite material. It should be mentioned that despite an increase in hardness, there is no considerable effect on the minimum torque of rheometry and density of the compounds.

The hardness of the outsole made from rubber rope ranges from 65 to 70 Shore A, so the material samples studied have the appropriate hardness for making outsole.

3.2. Results on the Water Resistance of Outsole Material

From the results depicted in Fig. 10, it can be seen following.

After soaking 5 outsole samples L1, L2, L3, L4, and L5 at 4 different time levels from 30 to 45 minutes, it was found that the water absorption capacity of the samples increased quite rapidly at 30 and 35 minutes of the sample. The rate of increase was rapid and reached the highest in sample L3 with 21.8%. Sample L1 had the smallest water absorption capacity of 19.5%. The water absorption gradually slows down at the 40 and 45 minute time levels. However, at 45 minutes, the highest water absorption reached 22.8% in samples L3 and L5. The samples absorb water at the above rate because the composition of the waste fibers contains water-absorbing molecules, causing capillaries to swell, leading to an increase in the mass of the sample. According to TCVN 8840-2011 standards for water resistance (water absorption less than or equal to 25% after 30 minutes), all tested samples meet the quality requirements.

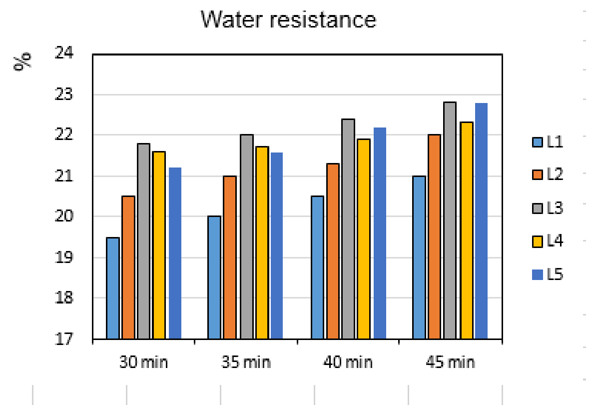

Fig. 10. Water resistance of outsole material

3.3. Results on the Dimensional Stability of Outsole Material

When evaluating the outsole of a shoe, dimensional stability is an important factor because it directly affects the durability of the product and the safety of use. Deformed soles can cause the entire shoe product to lose its shape and form, causing discomfort or imbalance. This criterion is also an important criterion in technical standards to ensure product quality and durability.

Survey on the dimensional stability of outsole material from Textile and Footwear industry scrap using TCVN 12733:2019. The results are shown in Fig. 11.

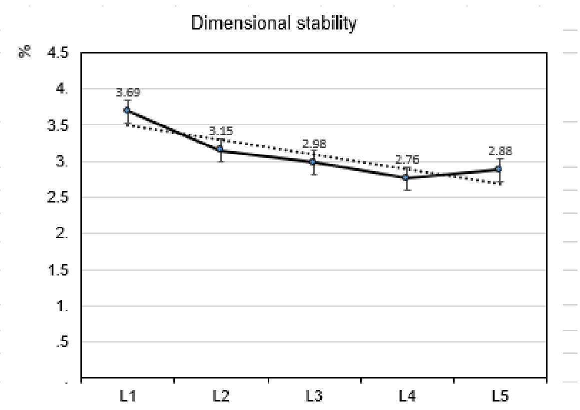

Fig. 11. Dimensional stability of outsole material

Five outsole material samples made from textile and footwear waste L1, L2, L3, L4, and L5 was tested dimensional stability. The shoe outsole samples were tested according to the regulations of TCVN 12733:2019. The results found that the samples had shrinkage in the range of 2.76-3.69%. Sample L1 had the highest shrinkage of 3.69 %, and sample L4 had the lowest shrinkage of 2.76%. The average shrinkage of all samples was 3.09%. The requirement for dimensional stability of shoe soles according to TCVN 8840-2011 is less than or equal to 2.5%. The research samples have dimensional stability greater than the required value by about 0.5%.

3.4. Research on the Compression of Outsole Material

When evaluating the load-bearing capacity and durability of shoes, the compression of the outsole and sole details is a property of interest. Through this property, the durability of the product can be evaluated. The results are shown in Fig.12.

Using 5 test samples: L1, L2, L3, L4, and L5 of shoe outsole material from textile and footwear waste, the compression energy was measured according to TCVN 10083:2013. The results showed that the compression energy ranged from 15.3 J to 18.8 J. The average compression of the test samples was 16.64 J. When the compression energy is large, it will create the material's ability to return to its original state. This helps the product withstand deformation well during use.

The values of the shoe samples have a small difference in compression. There is a close relationship between compression energy and elasticity. When the compression energy is large, it will create the material with the ability to return to its original state, helping the product withstand deformation well during use. This once again confirms the appropriate mixing ratio of the material components. The good connection between the elements in the material block helps increase the overall durability of the outsole. With the product being the outsole, it will help the user consume less energy, and run farther and faster. With the above experimental results, it can be concluded that the outsole material product ensures durability during use.

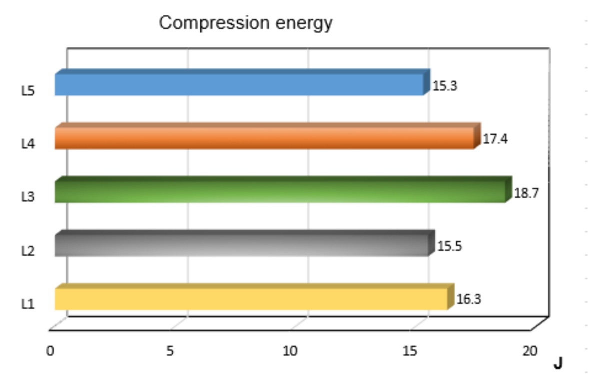

Fig. 12. Compression energy of outsole material

3.5. Research on the Abrasion Resistance of Outsole Material

For materials used for outsoles, abrasion resistance plays an important role. To evaluate the abrasion resistance of shoe sole materials from textile and footwear waste, use TCVN 12731:2019. For the test, samples L1, L2, L3, L4, and L5 of shoe sole materials were used, as in the previous property tests. The results are shown in the Fig. 13.

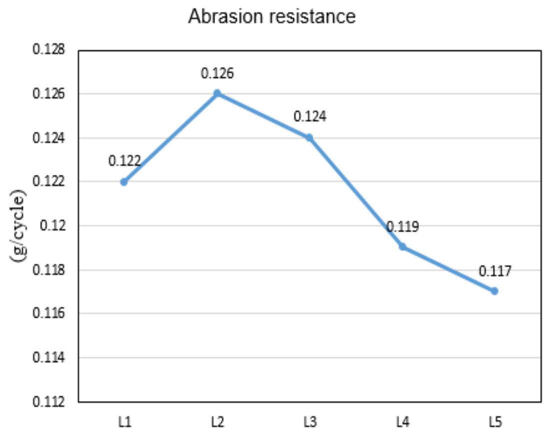

Fig. 13. Abrasion resistance of outsole material

The abrasion resistance of the shoe sole samples was tested, revealing that the shoe sole material sample showed the most wear, with a measurement of 0.126 g/cycle. Sample L5 exhibited a wear of 0.117 g/cycle, and the average abrasion resistance of the samples was recorded at 0.122 g/cycle. This indicates that the effective interaction between waste fibers, leather fibers, and rubber enhances spatial network density. The increase in spatial network density results from the strong interaction between the rubber base system and vulcanizing chemicals, as well as the waste fibers and leather fibers integrated into the rubber base. The exceptional compatibility and dispersion of waste fibers and leather fibers within natural rubber alter properties like mechanical strength and abrasion resistance. These findings are valuable for evaluating shoe outsole materials.

4. Conclusion

The properties of outsole material samples L1, L2, L3, L4, and L5 made from crushed fibers from small waste fibers and waste leather on natural rubber substrates were evaluated according to TCVN standards. The tested outsole material samples showed good tensile strength, tear strength, and hardness. This shows a certain compatibility between rubber materials, waste leather, and waste fibers, increasing the material's durability. This is a necessary property for products aimed at being outsoles.

The results of testing the important properties of shoe sole materials in this study show that these material samples are suitable for making shoe outsoles and meet the requirements of outsole materials according to TCVN 8840-2011.

This research result represents an effective solution to the issue of scrap waste in textile footwear enterprises. It creates new opportunities for the recycling of materials and the footwear manufacturing sectors while addressing a broader societal concern: establishing a green, circular economy within the Textile and Footwear industry.

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